BOSTON UNIVERSITY

GRADUATE SCHOOL

Dissertation

INTERFEROMETER DETERMINATIONS OF CERTAIN WAVELENGTHS, BETWEEN LAMBDA 3770 AND LAMBDA 4220, OF THE SECONDARY SPECTRUM OF HYDROGEN

by

Reginald Gage Lacount

(B.S., Boston University, 1928;

A.M., Boston University, 1933)

submitted in partial fulfillment of the

requirements for the degree of

Doctor of Philosophy

1936

1936
l
copy 1

Outline of the Thesis

Outline of the Thesis (continued)

INTERFEROMETER DETERMINATIONS OF CERTAIN WAVELENGTHS, BETWEEN LAMBDA 3770 AND LAMBDA 4220, OF THE SECONDARY SPECTRUM OF HYDROGEN

Introduction

Standards of wavelengths are desirable in the spectrum of any element, but perhaps in no element are they more desirable than in that of hydrogen. This lightest of atoms forms today, as it always has, a starting point for all attempts to gain insight into the structure of the atom. Since such attempts must depend largely on interpretation of the spectra of the elements considered, standards of wavelength in these spectra provide much needed guide posts by which to check theory and experiment.

The most accurate measurements of wavelength are absolute measurements or the wavelength of one line in terms of that of another. Such measurements are obtained from plates photographed with the aid of an interferometer. Since such measurements in the molecular spectrum of hydrogen have not been made below the region of $\lambda 4200$, it was decided to continue them down to the region of $\lambda 3750$. The work was done by crossing an etalon with a 30 foot Littrow grating spectrograph in the Rumford Room of the Spectroscopic Laboratory of the Massachusetts Institute of Technology. Several plates were taken with the crossed etalon and grating, and several with the grating alone, the latter to serve for interpolation measurements between lines measured with the aid of the interferometer, as well as for determining preliminary values of wavelength in calculating the interfermoeter measurements. The standard Pfund arc was used for comparison.

Historical

Measurements of wavelength in this spectrum date back to the visual measurements of Hasselberg in 1882 (1). Nothing of importance was done until 1922 when Merton and Barratt (2)

measured 1200 lines between λ6540 and λ3375, interpolating between lines from a standard Pfund arc. Tanaka (3) and Deodhar (4) each measured about 500 lines, using lines measured by Merton and Barratt as standards. But it was not until 1928 that much progress was made. In this year, Finkelnburg (5) took photographs in which he measured 3667 lines, of which 2000 had never been measured before. The standard Pfund arc gave the comparison spectra. Also, in this year Gale, Monk, and Lee (6) measured 95 lines on plates taken with a Fabry-Perot interferometer crossed with a grating. In addition they used these lines as standards, and measured 2969 other lines by interpolation. So far, they are the only observers who have applied the interferometer to the measurement of lines in this spectrum. Their measurements with this instrument did not go below λ 4100. The work on which this paper is based is an attempt to continue these measurements down to λ 3750. Mention should be made of the measurements made by Professor Kent (7) on lines in this spectrum photographed in 1927 at the Norman Bridge Laboratory of the California Institute of Technology. He has measured approximately 900 lines from λ3612 to λ4856. Because of refinements used on photographing these lines, and the use of a constant temperature comparator in measuring them, the importance of which I have dealt with elsewhere (8), their accuracy is probably fully as great as any made up to the present time, by the interpolation method.

Apparatus

Laboratory and Instruments

The Rumford Committee Room where the research was carried out is situated in the Eastman Spectroscopic Laboratory of the Massachusetts Institute of Technology. (9) It is about 40 feet long, 8 feet wide, and 8 feet high. The floor, with the exception of a small strip near the door at the end of the room, is insulated from the vibrations of the outer laboratory by the absence of rigid construction with the walls and floor

of the rest of the building. The floor is about 20 inches thick, and over it, at the end near the door, is a wooden platform suspended from the walls and floor of the outer laboratory. This allows one to move around in making adjustments on the source system during the photographic exposure, without tranmitting vibration to the optical system.

The temperature of the room is controlled by a thermocouple hung in the middle of the room. When the temperature rises, this causes a fan to force air into the room from an air shaft at the end of the room opposite the door. When the temperature drops, the fan is turned off, and two heating units are turned on. One of them is in front of the fan, and the other is half way along the wall towards the door. Each of these consists of 2 ordinary "sunbowl" heating coils, and an auxiliary fan placed behind each of them keeps the air within the room in constant circulation, thus providing more rapid and uniform response to the action of the coils. Ventrals in the door provide a means for air to pass out of the room. A recording Brown Potentiometer records the temperature in the room, continually. The temperature variation in this way was kept to within about .5 of a degree during 8 hour exposures.

An Anderson plane grating having a ruled surface of 9.7× 12.9 cm. and 15000 lines per inch was used for auxiliary dispersion. This was loaned, kindly, to Boston University by Johns Hopkins University. It was used in a Littrow mount, with a collimating lens consisting of an achromatic doublet of 30 foot focal length and 6 inch diameter. The lens and grating are supported by 2 concrete blocks, approximately 2 feet long on each edge, covered by a stone slab, about 4 feet x 2 feet x 2 inches. A similar block supports the slit and camera box at the other end of the instrument. A wooden frame about 2 feet square covered with wall board, and supported from the floor by three wooden trusses placed along its length, incloses the space between the camera box and grating. A slightly larger enclosure of similar construction surrounds

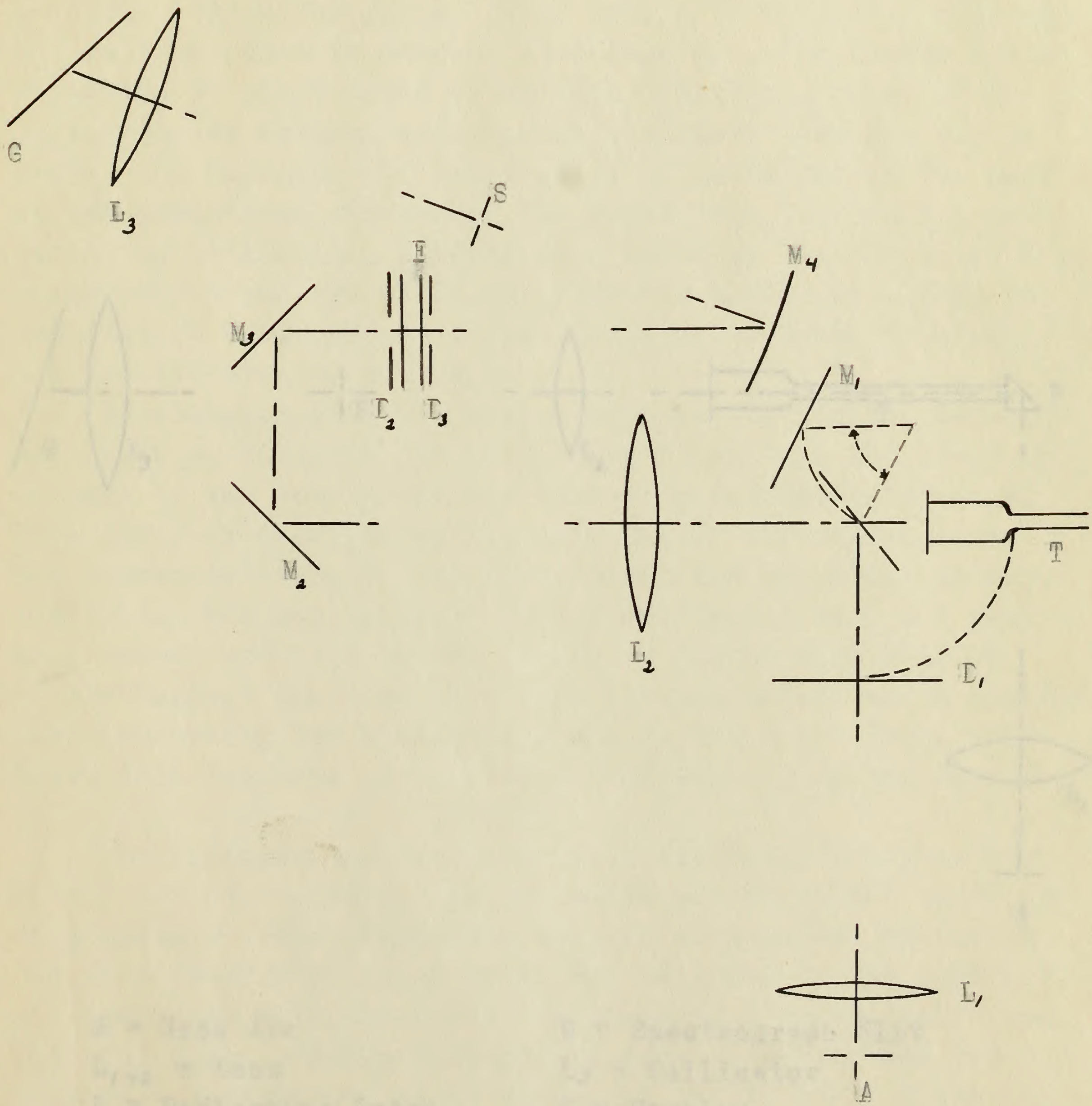
the grating and lens. At the other end of the instrument the slit is suspended from a steel frame which encloses the camera box, and carries the plate holder. The slit can be moved parallel to the optical axis, so that it can be placed in the same plane as the front of the photographic plate. It can be rotated about an axis parallel to the optical axis, so that the jaws can be set perpendicular to this axis, and also can be rotated about an axis perpendicular to the optical axis, so that the faces of the jaws may be set normal to the incident radiation. The plate holder can be rotated about a vertical axis at the center. The metal faces against which the plate is held by three spring clamps can be changed in curvature by means of set screws. All of this provides a means of bringing the spectrum into focus upon the plate. The entire plate holder can be moved parallel to the optical axis, to allow the center of the plate to be brought into focus. This motion is provided by means of a screw which causes the holder to slide along two steel ways screwed to a large steel base plate. The plate holder accommodates plates 2 inches × 22 inches.

The etalon used consisted essentially of two plane parallel glass plates, 65 percent silvered, held parallel, with their silvered sides towards each other by means of three spring clips controlled by set screws, which pressed them against a separator consisting of a cylinder of fused quartz. A separator of 10 mm. was used during this investigation.

Optical System

The optical system is shown diagrammatically in Plate I. Light from the hydrogen tube T is collected by the lens L_1 reflected by plane mirrors, M_2 and M_3, and brought to a focus on the diaphragm D_1 in front of the etalon. It then passes through the etalon and diaphragm D_3, is collected by the concave mirror M_4, and reflected into the slit S. The interference rings produced by the etalon are localized at infinity. Hence the concave mirror is placed at its focal length, 97.3cm. from the slit and therefore brings the rings to a focus on the slit. The diaphragm D_3 is placed at such a distance from

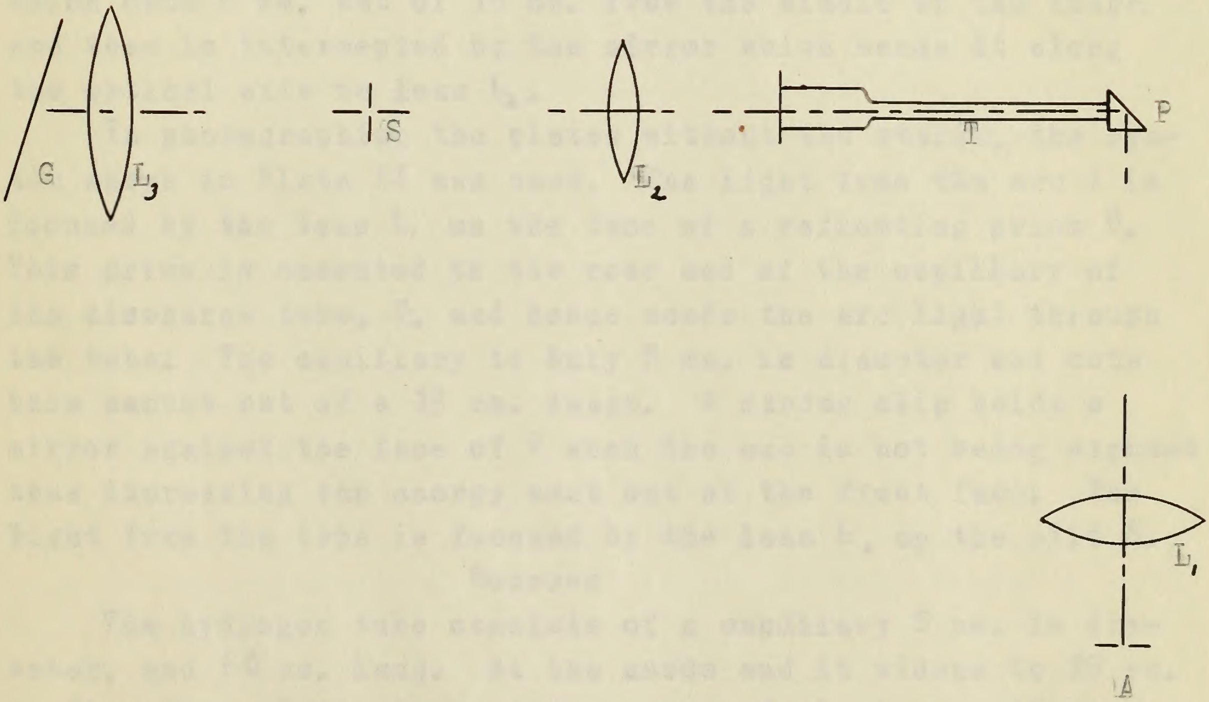
Plate I
Optical System With Etalon



A = Iron Arc	$M_{1,2,3}$ = Plane Mirror	S = Spectrograph Slit
$L_{1,2}$ = Lens	$D_{2,3}$ = Diaphragms	L_3 = Collimator
D_1 = Diaphragm	E = Etalon	G = Grating
T = H_2 Tube	M_4 = Concave Mirror	

Plate III

Optical System Without Etalon



A = Iron Arc S = Spectrograph Slit

$L_{1,2}$ = Lens L_3 = Collimator

P = Reflecting Prism G = Grating

T = H_2 Tube

the concave mirror that a real image of it is projected on the grating, and it is of such a size that the image of it just illuminates the entire area of the grating when the slit is wide. The diaphragm D_2 is of such a size that it cuts out all rays not passing through diaphragm D_3. The mirror M_1 is supported by a bed plate which will rotate and allow it to intercept the optical axis during the short time the arc is used. The remainder of the time it is moved out of the path of the light from the tube. The light from the arc A, is collected by lens L_1, brought to a focus on the diaphragm D_1, which cuts 8 mm. out of 13 cm. from the middle of the image, and then is intercepted by the mirror which sends it along the optical axis to lens L_2.

In photographing the plates without the etalon, the system shown in Plate II was used. The light from the arc A is focused by the lens L_1 on the face of a reflecting prism P. This prism is cemented to the rear end of the capillary of the discharge tube, T, and hence sends the arc light through the tube. The capillary is only 8 mm. in diameter and cuts this amount out of a 13 cm. image. A spring clip holds a mirror against the face of P when the arc is not being exposed thus increasing the energy sent out at the front face. The light from the tube is focused by the lens L_2 on the slit S.

Sources

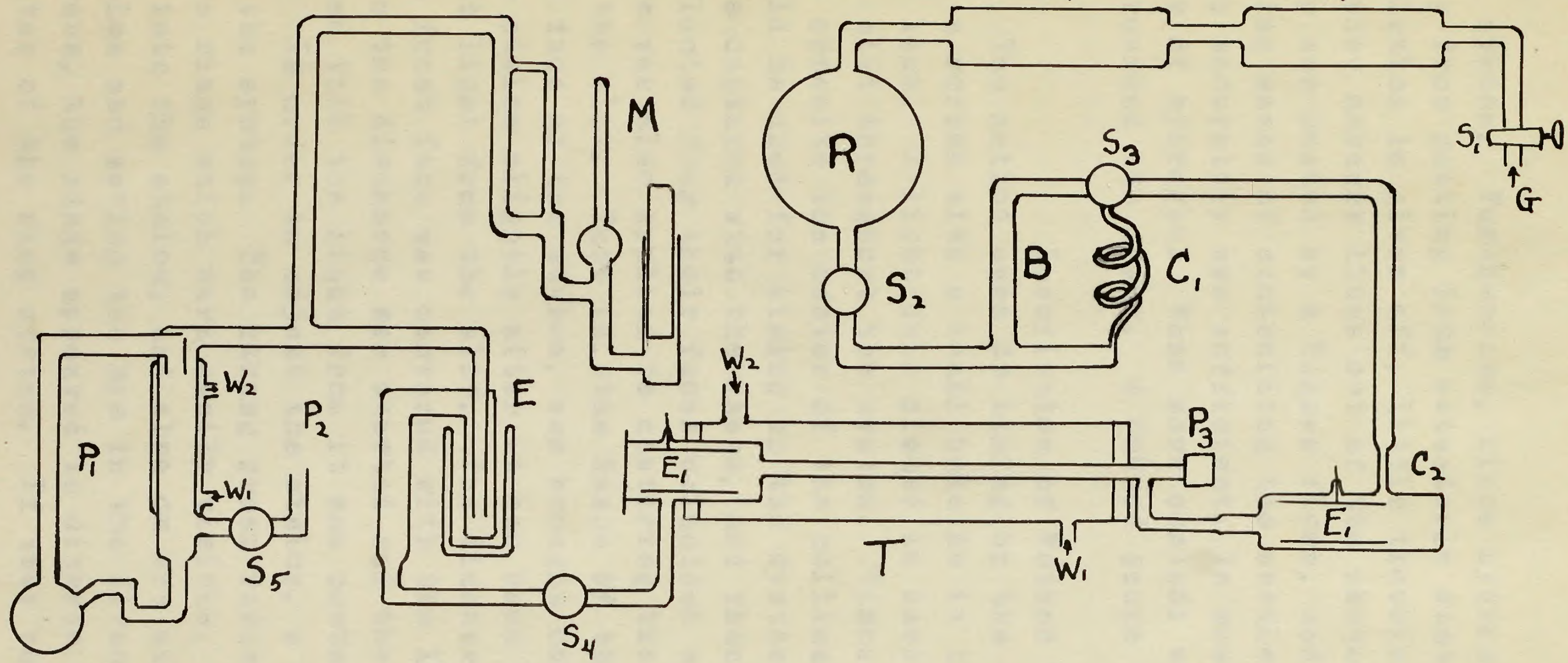
The hydrogen tube consists of a capillary 8 mm. in diameter, and 60 cm. long. At the anode end it widens to 18 mm. in diameter. Both electrodes consist of aluminum cylinders, the cathode chamber being below the back end of the capillary and connected with the latter by means of a branch tube from the same. The capillary itself is made of quartz and the electrode chambers of pyrex glass. A quartz cover glass is cemented to the front of the anode chamber. The capillary is surrounded by a cooling jacket through which water flows continually. This jacket also surrounds about half of the anode chamber, while the cathode chamber is kept cool by water from

a perforated rubber tube flowing over absorbent cotton bound on the chamber. The capillary is coated with a layer of platinum, by painting the inside with platinum bright paint, and then heating it slowly to a red heat, in a flame. It has been found that such a coating tends to adsorb atomic hydrogen on the walls of the tube, which is then combined with the atomic hydrogen passing through the tube to form H_2 molecules. A continuous flow of hydrogen was used during exposure to wash out impurities. A 5 K.W. Acme transformer supplies 170 milliamperes at 30000 volts to the tube. The cooling system was found to be adequate to keep the tube cool practically indefinitely, even with this amount of current.

The iron arc used was the standard Pfund arc operated at 220 volts and slightly more than 4 amperes. The arc was 15 mm. long, and projected an image of 13 cm. from the middle of which 8 mm. was taken and sent through the system. A rod of Bessemer steel providing the upper, positive pole, was surrounded by brass cooling fins. The lower and negative pole consisted of a bead of oxide of iron placed on the end of an iron rod, about 7 mm. in diameter.

The vacuum system is shown diagrammatically in Plate III. The hydrogen is generated electrolytically at G , is passed through 2 drying tubes A, containing CaCl and P_2O_5, and then sent to the reservoir R. From R it can be sent directly into the discharge tube through a short thick walled capillary at C_2, by using by-pass B, or, passed through the long, coiled, thick walled capillary C_1. This latter provides a means of controlling the flow of gas by a long capillary without the danger of breakage and use of a large amount of space as demanded by the ordinary thin walled capillary. After passing through the discharge tube, the hydrogen is sent first to the mercury trap F , this being set in a Dewar flask containing a slush of dry ice and acetone, and then to the mercury pump P_1. The gas is then sent to a motor driven oil pump which completes the exhaustion. The dry ice and acetone used in the mercury trap was found to be sufficient for keeping the mercury out of

PLATE III



The Vacuum System

G = H_2 Generator
A = Drying Chamber
R = Reservoir for H_2
$S_{1,2,3,4,5}$ = Stop Cock
B = Bypass
$C_{1,2}$ = Capillary
E_1 = Electrode Chamber

P_3 = Reflection Prism
T = H_2 Tube
W_1 = Water Intake
W_2 = Water Outlet
E = Hg Trap
M = Mcleod Gauge
P_1 and P_2 = Hg and Oil Pumps

the system. Furthermore, since hydrogen tends to prevent mercury from getting into metastable states, in which most of its radiation is given off, little trouble was anticipated in keeping mercury lines out of the photographs. The mercury pump was heated by a Bunsen flame, and a long wire rod providing means of controlling the needle valve of the latter very accurately was sufficient, in most cases, to control the flow of hydrogen. When more control was needed, the stop-cock S_3 provided the means. A McLeod gauge M indicated the pressure.

Description of Method Used

The method used in lining up the optical system was to put a screen with a small hole in it in front of the collimating lens. A light bulb placed in back of it cast an image of the slit throughout the system. Since the hole in the screen was opposite the center of the collimating lens, this image could be used for lining up the system. All lenses and mirrors were centered with the image, and then turned until the image reflected from their faces coincided with the incident beam. This was also applied to centering the rings from the etalon on the slit. That is, the image of the slit, reflected from the face of the etalon, was brought on the slit by turning the etalon slightly after it had been centered with the incident light from the slit. The discharge tube was moved till its front face was centered with the light from the slit, and then the discharge was started and the back end of the tube moved till the light from it was centered on the slit.

In order to adjust the etalon, a mercury arc lamp was put in the system. The strong green radiation from this source gave rings which were easily visible, both when looking directly into the etalon, and also on the slit. By locking into the etalon and moving the eye in the direction of one of the set screws, the rings appeared to diverge or converge towards the center of the ring system. If they converged, it meant that the distance between the mirrors increased in the direction of motion of the eye, and the screw in that direction was tight-

ened. If they diverged, the screw was loosened. In this way the rings were made to remain constant in size regardless of the motion of the eye. The image of these rings on the slit was used as a final check on theircentering with the slit.

Considerable difficulty was experienced in focusing with the Littrow mount, due to the great length of optical arm employed. The general procedure was to cut up the 22 inch plates employed into about 10 pieces each, and use these for trials. First, tilt plates inclined about 30° to the horizontal were exposed, thus showing roughly the horizontal position of best definition. This was done for the center and one end. Then a series of photographs were taken, both in front of and behind the best position as shown on the inclined plates. This showed the best position definitely. The center was focused first and then the two ends, the plate holder being rotated about its central axis.

The vacuum system was thoroughly exhausted down to less than .1 of a micron before an exposure was started. Then about six generator tubes of hydrogen were let into the reservoir, the latter being cut off from the rest of the system, during filling, by means of a stop cock (S_2, in Plate III). The stopcock over the generator, S_1, was then set so that with the reservoir connected open to the rest of the system through the capillary, the level of the solution in the generator tube remained constant. When the pressure was between .1 and .2 mm. of Hg, as governed by the Hg pump, the tube was started, using the low voltage taps on the transformer, and gradually increasing the voltage till the full value of 170 milliamperes was passing through the tube. Then the pressure was brought to as near a constant value, around .2 mm. of Hg, as possible. After the tube had been run this way for about an hour the exposure was started. A small direct vision spectroscope was mounted to take light from the side of the tube near the object position of the condensing lens in the front of the tube. This allowed the spectral conditions of the tube to be examined before and during the exposure. Too low

a pressure gave a strong atomic spectrum, and too high a pressure gave a weak secondary spectrum with a strengthened continuous spectrum. The presence of a leak was indicated by a strong band spectra, as well as by a decided reddening of the tube. Under the best conditions the tube gave a white light with a slightly pink tinge. Therefore, continual reading of the pressure gauge was made during an exposure. The arc exposure was divided into equal intervals, and distributed throughout the time of the tube exposure. It was found that a pressure of around .2 mm of Hg gave about the best results from the standpoint of intensity of secondary spectrum, and small amount of continuous background. For the exposures with the grating without the etalon, 4 hours was found to be sufficient for the tube, with 5 minutes for the arc. When the etalon was used, 12 hours were required for the tube, with 10 minutes for the arc. It should be mentioned that when the grating was used alone for dispersion, the diameter of condensing lens used for the arc was 1.75 inches, whereas with the etalon it was found necessary to use a lens with 3 inch diameter in order to get more than 3 rings on the plate. When the grating was used alone, the length of the arc was about 1 cm., and the current through it about 4.7 amperes, as compared with 1.5 cm. and 4 amp. with the etalon. The change was made necessary to avoid the assymetry in intensity of the rings due to a slight pole effect.

The photographic plates used were Eastman Spectroscopic plates, listed as type I-O. The developer and hypo were mixed from standard Eastman formulae, D-11 for the developer, and F-O for the hypo. The plates were developed for 5 minutes and fixed in the hypo for 20 minutes. The temperature of the solution was kept about 65° or 70° F.

Calculations

As mentioned above, the etalon, or Fabry Perot interferometer of fixed mirror separation, depends on the path difference between the beams passing directly through the two mirrors and the beams reflected between them an even number of times to give the interference rings. In Figure I, of Plate IV, the point O represents a source. OA is a beam which strikes the parallel mirrors HA and IB perpendicularly. Part of the beam will pass through at B and part be reflected back to A. A part of the latter will be reflected back to B again and the part of this second beam which passes through B will have a difference of path from the first beam which passes through at B of 2AB. If 2AB = $n\lambda$, where n = an integer, and λ = the wave length of the beam, then the 2 beams will produce constructive interference and a bright spot will be formed in the focal plane of the collecting lens or mirror. Similarly, a beam, OC, which makes an angle θ with the beam OA, will cause parallel beams to leave the mirror IB at D and F, respectively. If the path difference between these beams = $(n+1)\lambda$, then we have a bright spot formed again by the constructive interference of the two beams, after they are brought together by a lens. Again, a beam OE, which strikes the mirrors at such an angle that the path difference = $(n+2)\lambda$, forms a bright spot still farther from the line OB. It will be noticed that the successive beams leaving the mirror, IB, from any initial incident beam, are all parallel, and hence, will be brought together in the focal plane of the collecting lens. Furthermore, any beams making the angle θ with OA, even though not in the plane OAC, will produce a bright spot in the focal plane, and at the same distance from OB as that formed by OD. Any other point, such as O', which is part of the same extended source as that to which O belongs, will send out beams parallel to those of O, which will produce constructive interference when the corresponding parallel beams from O produce such interference. As a

result, beams from any point in the same extended source, parallel to OC, (treating this source as lying in a plane), are brought to the same focus by the collecting lens, and produce a bright spot there. Similarly, beams from any point in the same source, parallel to beams from O making an angle θ with OA, will produce bright spots somewhere around OB, at the same distance from OB, as the spot formed by OD. In this way a bright ring is formed. The same applies to beams parallel to OE, or making an angle α with OA. In this way, concentric rings are formed about B as a center. At the points between the rings, partial destructive interference is formed, destructive interference taking place halfway between the rings, and dark rings are formed there.

If the wavelengths of 2 beams differ by a very small amount, the angles which they must make with the normal to the mirrors, in order to produce constructive interference with their respective, successively reflected beams, differ very slightly, and the two ring systems are almost coincident. This appears to give one ring system with broadened rings. For this reason, if a spectrum line is produced by quite polychromatic radiation, this radiation will produce fuzzy interference rings. This is the case with the radiation photographed on the plates referred to in this paper, both from the iron arc, and from the hydrogen tube.

In order to understand the method of calculation used here, it is necessary to understand the basis of the formulae used. Figure 2, Plate IV, is a portion of Figure 1, enlarged. The difference of path of the rays XR and FT = (DE+EF) - DX.

But $\qquad EN = EF\cos\theta = DE\cos\theta$

Therefore $\qquad EF = EN/\cos\theta = DE$

$\qquad DE+EF = 2\ EN/\cos\theta = 2t/\cos\theta$, where t = optical distance between the mirrors.

Also $\qquad DX = FD\sin\theta$

But $\qquad FD = 2FN = 2EN\tan\theta$

And $\qquad DX = 2t\ \tan\theta\ \sin\theta$

Plate IV
Formation of Fringes By Etalon

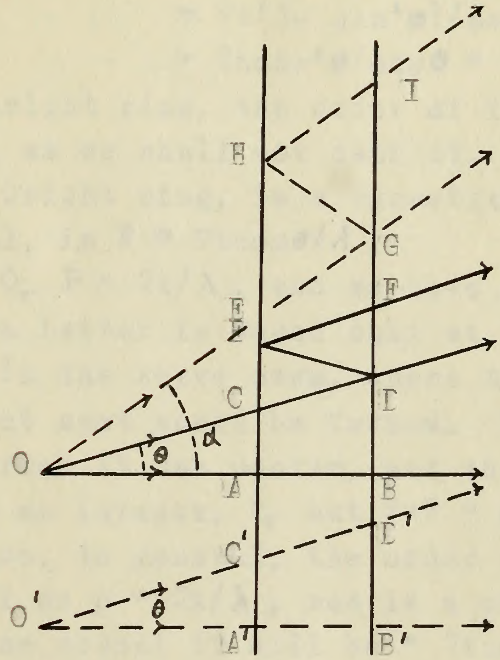


Figure 1

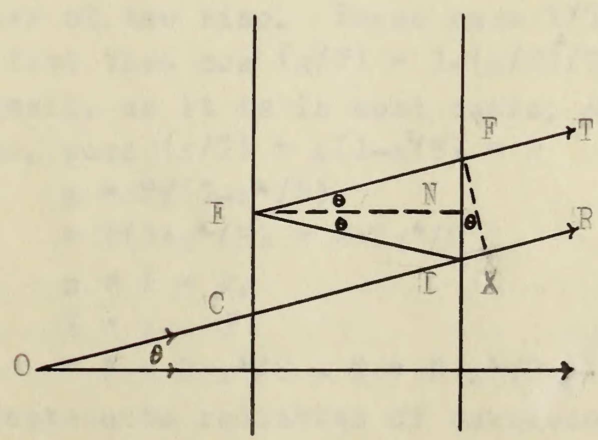


Figure 2

If the path difference is a whole number of wave lengths, then

$$n\lambda = (DE + EF) - DX$$
$$= 2t/\cos\theta - 2t \sin^2\theta/\cos\theta$$
$$= 2t(1 - \sin^2\theta)/\cos\theta$$
$$= 2t\cos^2\theta/\cos\theta = 2t \cos\theta$$

For any bright ring, the order of interference is an integer, n or, as we shall now call it, P. Therefore, the order for any bright ring, in a direction making an angle θ with the normal, is $P = 2t\cos\theta/\lambda$.

When $\theta = 0$, $P = 2t/\lambda$, and we have a case of normal incidence. The latter is found only at the center of the ring system. In the above case, where the order is an integer, P, a bright spot would be formed. In general, a bright spot is not formed at the center, and the order of interference is not an integer, P, but $P+E = p$ where E is a fraction. Hence, in general, the order of interference at the center will be $p = 2t/\lambda$, and in a direction making an angle θ with the normal it will be $= 2t\cos\theta/\lambda = p\cos\theta$. It should be noted that as θ increases, the order decreases, and hence is greatest at the center. For any bright ring, $P = 2t\cos\theta/\lambda = p\cos\theta$. If X is the angular diameter of a ring, then $X/2 = \theta$, since θ is subtended by the radius, and not the diameter of the ring. Hence $p\cos X/2 = P$.

From the fact that $\cos(x/2) = 1 - (x/2)^2/2! + (x/2)^4/4! + \ldots$ if x is very small, as it is in most cases, since we use only the inner rings, $p\cos(x/2) = p(1 - x^2/8) = P$

Therefore, $p = P/(1 - x^2/8)$

$$= P(1 + x^2/8) = P + Px^2/8$$

But $p = P + E$,

and hence $E = p - P$

$$= P + P x^2/8 - P = P x^2/8$$

If this represents radiation of wavelength λ, radiation of wavelength λ', will have a fractional order of interference at the center of $E' = P'X'^2/8$. Since the distance between the mirrors is 2t, which is constant

$$p = 2t/\lambda,$$
$$p' = 2t/\lambda' ,$$
and
$$2\,t = p\,\lambda = p'\lambda'$$
$$= (P+E)\,\lambda = (P'+E')\,\lambda'$$
Therefore,
$$\lambda' = \lambda\frac{(P+E)}{(P'+E')}$$
$$= \lambda\frac{(P+PX^2/8)}{(P'+P'X'^2/8)} = \lambda\frac{P(1+X^2/8)}{P'(1+X'^2/8)}$$
$$= \lambda P(1+X^2/8-X'^2/8)/P'$$

Hence, by measuring the angluar diameter X and X' and knowing the integral order P, the ratio of λ'/λ can be found. This method was used by such observers as Fabry and Perot,(10) Pfund(11), Fabry and Buisson(12), Burns(13), and others(14).

If θ = angular distance subtended at the projecting mirror by standard gauge marks on the slit, L', the linear distance between the same marks on the slit, D', the linear diameter of a ring on the slit, and F the focal length of the projecting mirror,

then
$$X/\theta = \tan X/\tan\theta = \frac{D'/F}{L'/F} = D'/L'$$
therefore,
$$X = \theta D'/L'$$
But, if the corresponding linear diameters of the ring and gauge marks photographed on the plate, are D and L, respectively, then, $D'/L' = D/L$,
since the magnification of the instrument would be the same for both D' and L'.

Hence,
$$X = \theta D'/L' = \theta D/L.$$
Therefore,
$$E = P\,X^2/8 = P\,\theta^2 D^2/8L^2$$
This is the form in which the observers mentioned above generally used the equation $E \doteq PX^2/8$. This equation requires that the etalon be removed after an exposure, a gauge plate be placed in front of the slit, and a photograph made to determine L. Also, θ must be determined in addition.

Another equation used at Mount Wilson, evolved by Babcock(15), and used in measuring the lines given in this

paper, saves considerable time and avoids errors incurred in the determination of θ and L.

If m = the magnification of the spectrograph for a ring, and θ, L, and F represent the same quantities as before,

then $\quad mL' = L$,

and $\quad L' = L/m$

Also, for small angles, $L'/F = \theta$

Hence, $\quad L/mF = \theta$,

and $\quad \theta/L = 1/mF$

Therefore, $\quad E = P\theta^2D^2/8L^2 = PD^2/8m^2F^2$

Furthermore, from the equation $p(1-X^2/8) = P = p-pX^2/8$

we obtain $\quad E = p-P$

$\quad = p-p+pX^2/8 = pX^2/8$

But it has been shown that $E = PX^2/8$

Therefore $\quad E = PX^2/8 = pX^2/8$

$\quad = PD^2/8m^2F^2 = pD^2/8m^2F^2$

If we set $\quad p/8m^2F^2 = K$,

Then $\quad E = KD^2$ for any ring

More generally, for the n^{th} ring, counting the innermost ring as the first, $n-1+E = KD_n^2$. If the diameters D_1 and D_2 of the first two consecutive rings are measured,

$\quad E = KD_1^2$

and $\quad 1+E = KD_2^2$

Whence, $\quad 1 = K(D_2^2-D_1^2)$

and $\quad K = 1/(D_2^2 - D_1^2)$

This holds for any two consecutive rings near the center of the system. This equation may also be written as

$$K\lambda = \lambda/(D_2^2 - D_1^2),$$

where λ = the wave length of any line on the plate.

By assuming that the magnification m, is constant for the entire plate, we can set

$$K\lambda = p\lambda/8m^2F^2$$

$$= 2t/8m^2F^2 = \text{a constant for the entire}$$

plate.

The method of using this constant in obtaining the results given in this paper is best illustrated by a few examples from one of the three plates measured.

On this plate and one of the others, the diameters of the second and fifth rings were measured whereveer possible, and the difference of the squares of the diameters divided by the difference of the numbers of the rings, thus giving an average for the difference of the squares of the diameters of consecutive rings. For example, in the case of the second and fifth rings, we have $D_5^2 - D_2^2 /3$, instead of $D_2^2 - D_1^2$ for the first and second rings. In this way, any errors in the measurement of the diameters were divided by 3. If the fifth ring was difficult to measure, the fourth ring was taken. This method also avoided the errors caused by measuring the first ring, since the inner rings were wider and more poorly defined, than the rings farther out from the center.

The plates were measured with a Gaertner comparator, by setting them perpendicular to the carriage, so that the diameter of the ring being measured was parallel to the horizontal crosshair in the telescope. The long wave length end of the plate was placed towards the observer, and the readings made and recorded under the title "Red Lower", as shown in Table I, Plate V. Four settings are made on the middle of each segment, two approaching the vertical cross-hair from the left, and two from the right. Ten standard iron lines, spaced uniformly across the plate, were measured first. The first column gives the number of the ring measured.

The second column contains the wave length of the iron line as obtained from the list of standards accepted by the International Astronomical Union in 1928.

The third column contains the readings in centimeters made on the ring segments at the left of the center, as seen through the telescope.

The fourth column contains the corresponding readings for the segments at the right of the center.

The fifth column contains the difference of the means of the readings of the left and right segments of each ring, as given at the foot of each set of readings. This differ-

ence is D, the diameter of the ring.

The sixth column contains the apparent relative intensity, I, of the line, 0^4 representing a very weak line, 0 a moderately strong line, and 3 a very strong line.

After the ten iron lines were measured in this way, the plate was removed, turned end for end, so that the red end was away from the observer, and a corresponding set of readings taken and recorded under the title "Red Upper".

In Table II, the first and second columns are the same as in Table I, but the third column contains the diameters of the rings obtained as described above for the plate set "Red Lower" and "Red Upper".

The fourth column contains the means of these two determinations of the diameters for each ring. These are the values of D used for the final determinations.

The fifth column contains the squares of these diamteters.

The sixth column contains the difference of these squares, divided by the difference of the ring numbers, α and β, as previously described.

The seventh column contains the values of the wave-length divided by the average difference of the squares of the diameters of consecutive rings, as given in the sixth column for each line. These are therefore determinations of the plate constant $K\lambda$, as previously described. The division is carried out to the nearest integer. Corresponding values are calculated for all ten lines. The mean of the plate constants for the ten lines is taken for the final value. As a check, the average deviation from the mean is determined, and any gross errors are discarded. The final value is then determined as the mean of the remaining plate constants. It was not found necessary to discard more than one of these constants out of ten for any of the three plates. Babcock says that in practice it is found that the probable error for one determination of the plate constant is about 0.6%. On the three plates used

PLATE V

Table I

Fe Standards Red Lower

Ring	Standard λ	Left	Rt.	Lm-Rm = D	I
2	3767.194	3.557	4.782		
		.556	.785		
		.549	.782		
		.556	.781		
		3.555	4.783	1.228	0
5					
		2.934	5.415		
		.933	.419		
		.932	.416		
		.936	.415		
		2.934	5.416	2.482	

Table II

Ring	Standard λ	D Red Lower / Red Upper	Mean D	D^2	$\frac{D_\alpha^2 - D_\beta^2}{\alpha-\beta}$	$\frac{\lambda}{\frac{D_\alpha^2 - D_\beta^2}{\alpha-\beta}}$
2	3767.194	1.228				
		1.239				
			1.234	1.523		
5		2.482				
		2.471				
			2.477	6.136	1.538	2449
2	3787.883	1.133				
		1.137				
			1.135	1.288		
5		2.420				
		2.430				
			2.425	5.881	1.531	2473

in this work it ranges from 0.2% to 0.5%. Furthermore, he says that the assumption of constant magnifiaction for the entire plate is allowable, even for a Littrow spectrograph of as small as 18 feet focal length.

In order to obtain the optical thickness of the etalon, it is necessary to know the value of the order of interference at the center. The method used to obtain this order is shown in Table III, Plate VI.

The first two columns are the same as in Table II.

The third column consists of the values of the plate constant $K\lambda$, divided by the wavelength for each line, and hence gives the values of K for each line.

The fourth column contains the values in the third column, multiplied by the squares of the diameters for each line. The values obtained are thus KD_n^2 which = $E+(n-1)$, as previously shown, where E = the fractional order, and n = the number of the ring.

From the two values of $E+(n-1)$ for each line, the mean value of E is obtained and recorded in the fifth column.

In order to find the integral order of interference the procedure is as follows. A micrometer determination of the thickness of the etalon must be used as a starting point, unless a previously determined optical thickness is available. In the example given, the latter, obtained from a previous plate, was known and used. But the procedure is the same as that in which the micrometer determination is used. In the sixth column, the double thickness of the etalon, 2t', thus obtained and given at the top of the column, was divided by the standard value of the wavelength of one line, λ_1, to the nearest integer. This is a trial value of the integral part of the order. To this is added the observed fractional order. The order thus obtained, and shown as the first value in column 2, Table IV, Plate VI, is correct in its fractional part, but may be incorrect in its integral part.(16) The integral part will be incorrect, unless the value of the thick-

ness of the etalon used in calculating it is the true value.

The next step is to multiply the entire order by the value of the wavelength of the line being used, and thus obtain a trial value of the double thickness of the etalon. This thickness, 2t", is given at the top of the second column of Table IV. The first column gives the standard wavelengths of the iron lines, the second iron line differing by not more than 50 A.U. from the first, the others lying farther away in the same direction. The trial thickness given at the top of the second column is divided by the values of the wavelengths in the first column, and the results recorded in column two. These are trial values of the orders for the different lines. If the fractional parts do not differ from the correct fractional parts, as given in column 5, Table III, by more than a few units in the second decimal place, we know that the trial value of the thickness, and hence the trial value of the order for the first line, is correct. If the fractional orders do not agree with the correct fractional parts, then we know that the integral part of the trial order for the first wavelength is not correct. Hence, one unit should be added or subtracted from the first trial order, and the above procedure repeated. After a few such trials, a correct value of the integral order for the first wavelength will be obtained, as shown by the fact that the fractional parts of the orders for the other lines agree with the correct values. This agreement must hold for at least four lines if the result is to be dependable. On the three plates measured, nine or ten lines were used. It will be noticed that the fractional parts of the values in column 2, Table IV, do not agree with the correct fractional parts in column 5, of Table III. Hence one unit is added to the trial value of the order for the first wavelength, λ_1, and the procedure repeated, as described above. This time, agreement of the fractional parts with the correct values is obtained, as shown in column 3, of Table IV. As a check, one more unit

is added to the order for λ_1, and the procedure repeated. This time we get disagreement of the fractional parts again, as shown in column four. Hence we know that the results in column 3 are correct.

In cases where the micrometer thickness is used for a starting point, the first value obtained for the trial integral order of λ_1 may differ by many units from the correct integral order. In a case of this kind, considerable time is saved by using the following formula. If F_2' is the first fractional order of interference obtained for the wavelength, λ_2, of the line next to λ_1, by using the first trial thickness, t", F_2 is the correct fractional order, such as is found in column 5 of Table III, then the expression

$$\frac{F_2' - F_2}{1 - \frac{\lambda_2}{\lambda_1}}$$

will give a rough value of the error in the integral order for λ_1 from which t" was obtained. Then by adding or subtracting an integer to the integral trial order, a few times, as described above, a correct value of this order will be obtained.

In order to get the true thickness of the etalon, we take the integral parts of the orders in column 3, add the exact fractional parts as given in column 5 of Table III, and multiply the results by the known wavelengths for each line. This gives us a list of values of 2t as shown in Table V, Plate VII. The mean of these values gives the final value of 2t. In the plates measured it was found necessary to throw out one line, as a poor line,* but from the other nine lines, nine values of 2 t were obtained to use in determining the final value of 2t.

*The values of 2t calculated for this line differed widely from the corresponding values calculated for the other nine lines.

PLATE VI

Table III

Ring	Standard λ	$\frac{K\lambda}{\lambda}$	$\frac{K\lambda}{\lambda}$ $D^2=E$	Mean E	$\frac{2t'}{\lambda_1}$
		($K\lambda=2483$)			$2t' = 18.564908$
2	$\lambda_1 =$ 3767.194	.6591	1.004		
5			4.044	.024	49280.
2	3787.883	.6555	.844		
5			3.855	.850	
2	3865.526	.6423	1.286		
5			4.382	.384	
2	3920.250	.6334	.844		
5			3.837	.841	

Table IV

Standard λ	$\frac{2t''}{\lambda_n}$	$\frac{2t'''}{\lambda_n}$	$\frac{2t''''}{\lambda_n}$
	$2t''=18.564741$	$2t'''=18.564117$	$2t''''=18.565487$
3767.194	49280.024	49281.024	49282.024
3787.883	49010.86	49011.85	49012.83
3865.526	48026.42	48027.40	48028.35
3920.260	47355.89	47356.85	47357.79

The process of measuring the hydrogen lines, and determining the fractional order is the same as with the iron lines, except that approximate values of the wavelength are known, instead of accurately known wavelengths. In fact, the approximate values should be known to within .01 A.U. This necessitates making a preliminary measurement of the wavelengths. The preliminary values used in this paper were taken from the interpolation measurements of Professor Kent, which are given to three decimal places in A. U. Also, the plate constant used is the one determined by using the iron lines.

Table VI, Plate VII, gives the values of E for four hydrogen lines, obtained in the same way that the fractional parts of the orders of the iron lines were obtained. In the third column, the value of 2t, calculated as described above, is divided by the approximate wavelength of the hydrogen lines. These give trial orders, P', for the hydrogen lines. If they do not differ by five or more units in the first decimal part of the order, from the correct fractional parts, we may assume that the integral order is correct. This is so in the example shown, as can be seen from observation of column three. In general it will be so for wavelengths known accurately to .01 A. U.

The final step is shown in column 4, where the integral part of the order in column 3 is added to the observed fractional part from column 2, and the result divided into 2t, to get the refined value of the hydrogen wavelengths.

PLATE VII

Table V

Standard λ	$2t = p\lambda$
3767.194	18.565117
3787.883	18.565115
3865.526	18.565110
3920.260	18.565112

Table VI

Approx. λ	E	$\frac{2t}{\lambda'} = p'$	$\lambda = \frac{2t}{p}$
3771.504	.636	49224.68	3771.507
3706.595	.323	48899.36	3796.598
3808.032	.532	48816.59	3803.037
3861.512	.315	48077.30	3861.511

Explanation of the Table

Table VII on page 29 shows the final values of the wavelengths obtained for each plate, together with the means of these values for each spectral line. All values of wavelengths are given in A. U.

Column 1 contains the integral values of the wavelengths(λ).

Column 2, (K), shows the fractional values of the wavelengths in thousandths of an A. U. obtained by Professor Kent from his grating measurements, and used for preliminary values in this investigation.

Columns 3, 4, and 5 show the fractional values of wavelength in thousandths of an A. U. obtained from the three plates measured. The number at the head of each column gives the number of the plate, and the letter (L) or (K) signifies that the plate was measured by the writer or Professor Kent, respectively.

Column 6 contains the weighted means of these values for the three plates. Plates 238 and 244 were each given twice the weight of plate 243 for reasons which will be mentioned later.

Column 7 shows the probable error (P.E.) for each of these means, in .001 A. U.

Column 8 shows the difference between Professor Kent's values (K) and the writer's mean values (L) of fractional wavelengths in thousandths of an A. U.

Column 9 contains the means of the values obtained by Finkelnburg, (F) and Gale, Monk, and Lee. (G)

Column 10 shows the difference between the above mean values, and the writer's mean values of fractional wavelength in thousandths of an A. U.

Table VII

λ	K	(L) 238	(L) 243	(K) 244	Mean	P.E.	K-L	F&G	F&G-L
3771	504	505	507	505	505	.33	-1	493	-12
3796	595	595	598	596	596	.49	-1	590	-6
3803	032	032	036	033	033	.65	-1	.027	-6
3861	512	508	510	507	508	.49	4	495	-13
3863	211	211	213	211	211	.33	0	200	-11
3869	940	939	943	940	940	.65	0	935	-5
3871	601	597	603	598	599	1.1	2	589	-10
3879	531	532	537	533	533	.82	-2		
3924	414	414	418	416	416	.65	-2	396	-20
3962	339	336	340	336	337	.82	2	334	-3
3982	567	566	571	567	567	.82	-0	560	-7
3986	927	930	934	933	932	.82	-5	921	-11
3990	040	038	042	039	039	.65	1	034	-5
4028	341	340	341	340	340	.16	1	330	-10
4043	570	569	572	568	569	.65	1	565	-4
4069	637	633	637	632	633	.82	4	632	-1
4072	964	963	964	964	964	.16	0	959	-5
4078	843	838	840	840	839	.82	4	848	9
4082	385	383	385	382	383	.49	2	383	0
4087	751	748	754	750	750	.98	1	750	0
4133	989	998	002	000	000	.65	-11	997	-3
4159	309	313	315	312	313	.49	-4	311	-2
4171*	306	305	310	307	307	.82	-1	308	1
4175	160	159	166	162	162	1.1	-2	164	2
4177	111	110	113	113	112	.65	-1	119	7
4179	592	588	594	590	590	.98	2	594	4
4180	104	107	112	108	108	.82	-4	108	0
4182	164	169	171	168	169	.49	-5	168	-1
4195*	669	670	674	670	671	.65	-2	671	0
4199	787	789	793	790	790	.65	-3	790	0
4209	168	169	174	169	170	.98	-2	172	2
4212*	498	500	503	500	501	.65	-3	502	1
4222	520	520	525	524	523	.98	-3	516	-7
4223	938	941	944	942	942	.49	-4	938	-4

Discussion of Results

While comparing the writer's values of wavelengths for each plate with Professor Kent's values, it was noticed that the values for the plates 238 and 244 agreed much more closely with each other than with the values for plate 243. For example, the average deviation of the values for plate 238 from Professor Kent's values was .0021 A. U., that for plate 244 was .0025 A. U., and that for plate 243 was .0039 A. U. Also, the values for plate 243 were systematically higher than those for the other plates, or those of Professor Kent. For instance, on plate 238 there were 12 values higher, and 17 values lower than the corresponding values obtained by Professor Kent. On plate 244 these differences were 19 values above, and 11 values below, and on plate 243 they were 29 values above and 1 value below, all compared with Professor Kent's values. This divergence of the values of plate 243 from the values for the other plates, led the writer to put about twice as much confidence in plates 238 and 244 as in 243, and hence the plates were weighted accordingly in obtaining the mean. It should be mentioned that all of the iron lines and 15 of the hydrogen lines on plate 243 were remeasured and the plate constant and etalon separation recalculated, before the values were accepted. With the exception of the atmospheric pressure, conditions while exposing plate 243 were the same as while exposing plate 244, so that a pressure change may be the cause of the above divergence of values. However, the writer believes that by giving twice the weight to the other two plates, it is safe to use plate 243 in obtaining the final mean values of wavelength.

The value of the slit width used in exposing plate 238 was .8 mm., while that for the other plates was .4 mm. Also the second and third, or first and second rings were measured on plate 238, whereas the second and fifth rings were measured on the other plates. Also, Professor Kent measured plate 244

and the writer measured plates 238 and 243. But in spite of this difference in slit width, method of measurement, and observer, values for plate 238 were remarkably close to values for plate 244. This justifies the writer's confidence in these two plates.

As can be seen from column 7, with the exception of two wavelength values, in which the probable error is .0011 A. U., the probable error of all values obtained is less than .001 A.U. and for the majority of values is less than .0007 A. U. They are systematically greater than the means of Finkelnburg and Gale, Monk, and Lee by .0036 A. U., as compared with only .001 A. U. greater than the means of Professor Kent. The average deviation of the writer's values from the means of Finkelnburg, and Gale, Monk, and Lee is .0052 A. U. while that from Professor Kent's means is only .0024 A. U.

It is interesting to note that three of the lines measured by the writer were also measured with an interferometer by Gale, Monk, and Lee. These lines are starred in Table VII. The comparison of these values, with the corresponding ones of the writer's, follows.

Integral λ	Gale, Monk, and Lee	Lacount
4171	308	307
4195	674	671
4212	498	501

It will be observed from Table VII that the writer's values are in better agreement with the means of Finkelnburg, and Gale, Monk, and Lee, than with the values of the latter alone, as far as the above three lines are concerned.

It is of interest, in this connection, to note that the writer's values are slightly less in error than those of the interferometer measurements of Gale, Monk, and Lee, in which the maximum probable error was about .0035 A. U. and the majority could only be said to have a probable error of less than .0012 A.U.

Also, Finkelnburg's values, obtained from grating plates, had a probable error ranging from .0035 A. U. for strong lines to about .007 A. U. for weak lines. Under these conditions, the close agreement of the writer's values with those of Professor Kent gives considerable weight to the accuracy of the latter values.

Summary

The region of the secondary spectrum of hydrogen between λ3760 and λ4250, was photographed on three plates, using a 10 cm. etalon crossed with the thirty foot Littrow grating spectrograph in the Rumford Committee Room of the Eastman Spectroscopic Laboratory of the Massachusetts Institute of Technology. Thirty-four lines between λ3771 and λ4223 were measured on all three plates, and the means determined. For all of the latter, except two, the probable error was found to be less than .001 A. U.

The theory of the etalon, and the method of reduction of wavelengths from interferometer spectrographs, together with the derivation of the formulae used therein, have been outlined.

In conclusion, the writer wishes to express his appreciation to Professor Kent for his many helpful suggestions, and for the privilege of working in such a well equipped laboratory and with such fine instruments. In connection with the latter, the writer wishes to acknowledge his indebtedness to the Massachusetts Institute of Technology for the great facilities placed at his disposal, and in particular to Professors Harrison, Boyce, and Stockbarger, for their many helpful suggestions during the course of the work, and to Dr. Humphrys for his valuable suggestions in connection with the evaluation of the plates.

The writer is deeply indebted to Dr. Dieke of Johns

Hopkins University for the loan of the grating used in the research, and to Mr. Babcock of Mt. Wilson Observatory for his many helpful suggestions during the entire course of the research.

The writer also wishes to express his appreciation to Mr. Taylor and Mr. Kildare for their valuable aid in doing the glass blowing, and to his wife, M. Irlene Lacount, for the typing of this paper.

The aid of a grant from the Rumford Committee of the American Academy of Arts and Sciences to Professor Kent, made this research possible.

Bibliography

(1) Hasselburg,	Phil. Mag. 5. 17, 329, 1882
(2) Merton, T.R. and Barratt, S.	Phil. Trans. Roy. Soc. A. 222, 369, 1922
(3) Tanaka, T.	Proc. Roy. Soc. A. 108, 592, 1925
(4) Deodhar, D.B.	Proc. Roy. Soc. A. 113, 429, 1926
(5) Finkelnburg, W.	Zeits. Fur Phys. 52, 27, 1928
(6) Gale, H.G., Monk, G.S., and Lee, K.O.	Astrophys. Jour. 67, 89, 1928
(7) Kent, N.A.	Unpublished Work
(8) Lacount, R.G.	M.A. Theses - Boston Univ. 1931
(9) Compton, K.T.	Physics 2, 205, 1932
(10) Fabry, C., and Perot	Astrophy. Jour. 15, 73, 1902
(11) Pfund, A. H.	Astrophy. Jour. 28, 197, 1908
(12) Fabry, C., and Buisson, H	Astrophy. Jour. 28, 169, 1908
(13) Burns, K	Bul. Bur. Stand. 12, 179, 1915
(14) Baly, E. C. C.	"Spectroscopy", First Edition, Longmans, Green and Co. 1927
(15) Babcock, H. D., and St. John, C. E.	Astrophys. Jour. 42, 231, 1915
(16) Williams, W.E.	"Applications of Interferometry", E.P. Dutton and Co., Page 85.

Autobiography

The writer was born on May 27, 1905, in Gardner, Massachusetts. He is the son of Rev. J. Edwin and Sarah Gage Lacount He graduated from the High School in Somerville, Massachusetts, in June, 1923. He attended the Providence Technical High School from 1923 to 1924, and entered Brown University in September 1924. In September, 1926, he transferred to Boston University and received his B. S. degree from that institution in June 1928. From 1928 to 1930 he studied Aeronautical Engineering and Physics at the Massachusetts Institute of Technology. In August, 1930, he was married to Miss M. Irlene Murray, and in September of that year, he accepted the position of instructor in Mathematics and General Science, at the High School of South Hadley, Massachusetts. In June, 1932, he resigned from this position, that he might engage in graduate study. In September, 1932, he entered Boston University Graduate School, from which he received his M. A. degree in June, 1933. From that time until the present, he has been engaged in graduate study at this institution.